# Deep-learning algorithms for choroidal thickness measurements in high myopia

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Despite the importance of the choroid in the physiology of the retina, it could not be properly examined until the introduction of the last generation of optical coherence tomography (OCT). Among others, functions of the choroid encompass blood supply for the retinal pigmented epithelium (RPE) and the photoreceptors, thermoregulation, or secretion of growth factors (1). It is mainly composed of blood vessels but also some stroma. A number retinal pathologies were suspected to be related to choroidal disorders, but it could not be confirmed until the introduction of swept-source OCT (SS-OCT) or the enhanced-depth-imaging (EDI) in case of the previous spectral-domain OCT (SD-OCT). Now it is possible to measure with precision choroidal thickness and sometimes even the choriocapillaris, which is the thinnest layer of the choroid and it lies just beneath the RPE and Bruch's membrane.

Some retinal disorders have been described and its pathophysiology has been better understood because of a deeper and more detailed study of the choroid. For example, the pachychoroid spectrum is a group of pathologies whose common characteristic is a thick choroid (2). Some others present a thinned choroid, such as age-related macular degeneration, retinal angiomatous, proliferation, high myopia (HM), or diabetes mellitus (DM) (3). In the latter, the thinning takes place even prior to the development of diabetic retinopathy (4). Choroidal thickness (CT) varies even with age, race, axial length or day time (3). In conclusion, the choroid plays an important role in the pathophysiology of a considerable number of retinal disorders and may be the underlying cause of some of them. Therefore, the possibility of measuring with accuracy its thickness has become of interest in ophthalmology.

SD-OCT use a wavelength of 840 nm and an interferometer with a high-speed spectrometer, which enables a higher image resolution (around 5–10 µm) and a scan rate of 20,000–80,000 A-scans per second (5). This enabled a detailed resolution of retinal layers for the first time, but it was not enough for imaging choroid accurately. The last generation of OCT is the SS-OCT, which uses a longer wavelength of 1,050 nm and so it provides an even higher resolution of 3–5 µm, as well as a scan rate of 100,000 A-scans per second (6). This was the first time that the choroid could be imaged with precision. An alternative for the former OCT was the EDI technology, which enables a good visualization of both posterior vitreoretinal and choroidal structures, as well (7).

Hence, some years ago research started focusing on the choroid. It has been found that it follows an irregular pattern (8). CT is thicker in superior-central macula and it gets thinned when distancing from it, especially in nasal and temporal sides. However, it seems that this own CT pattern varies depending on the systemic or ophthalmological disorder (3), and not all the choroid gets altered in a similar way. This is the reason why not only subfoveal CT should be measured, but all the choroid in the macular area should be revised. OCT slab analysis may be adequate in some cases, and in fact their measurements have been widely used by researchers. OCT slabs at different positions on the macula are therefore recommended.

**Table 1** Main features of some recently introduced deep-learning algorithms for automatic measurements of the choroid

| Authors | Eyes | Type of OCT |
|---|---|---|
| Li *et al.* (11) | HM | SS-OCT (Atlantis DRI, Topcon) |
| Zheng *et al.* (16) | non-nAMD | SS-OCT (Carl Zeiss) |
| Sun *et al.* (17) | Myopia | SS-OCT (Atlantis DRI, Topcon) |
| Zhou *et al.* (18) | Age | SS-OCT (Plex ELITE, Carl Zeiss) |
| Zhang *et al.* (19) | Healthy | SD-OCT and SS-OCT (Topcon) |
| Lee *et al.* (20) | Different patients | SD-OCT (Cirrus, Carl Zeiss) |

HM, high myopia; AMD, age-related macular degeneration; nAMD, neovascular age-related macular degeneration.

There are two possibilities for measuring CT: manual and automatic measurements. As expected, automatic measurements reduce variability, although there is always a little possibility of scan artefacts (9). In addition, manual measurements take longer time to be performed. Therefore, the development of internal algorithms for OCTs is essential for a precise and adequate research involving choroid. Most of actual OCTs include an internal algorithm in order to give automatic measurements of retinal layers and sometimes of the choroid. Despite using SS-OCTs, the choroid is usually more difficult to be measured than retina. In case of those disorders within the pachychoroid spectrum, the choroid is so thick that its limit with sclera is not always easily seen, and consequently limits are hard to be established. On the other hand, some other ophthalmological disorders such as HM may become difficult to be detected, too. HM is characterized by the presence of posterior staphyloma, which is the result of an abrupt scleral thinning together with posterior elongation of the ocular globe (10). This implies that choroid presents abrupt changes in shape and direction, and automatic measurements may not be precise and artefacts should be expected.

Deep-learning algorithms have been developed for some retinal pathologies, but little has been done for HM eyes. Li *et al.* (11) recently published their work, proposing a deep learning algorithm to segment choroid automatically in these patients. This deep learning algorithm is based on a group-wise context selection network. They used the SS-OCT Atlantis DRI-1 (Topcon Corp., Tokyo, Japan) and examined the 9 regions included in the ETDRS grid after performing 12-line radial scans centered on fovea. This algorithm showed good results in detecting HM patients, with a mean intersection-over-union of 87.89±6.93, a mean dice similarity coefficient of 93.40±4.10, a mean sensitivity of 92.81±6.34, and a mean specificity of 99.66±0.52. This high specificity stands out among the other validation parameters. Intraclass correlation coefficients (ICC) were calculated for the 9 ETDRS sectors and they ranged between 0.944 and 0.988. All these values show that the developed algorithm by this research group is valid and useful, and may become very useful in future research involving HM patients. This group has previous publications about automatic segmentation of the choroid, with promising outcomes, as well (12).

Accurate automatic CT measurements represent the perfect option for analyzing the relationship between stromal and luminal choroidal areas. This method has been used to differentiate the composition of the choroid, and the choroidal vascularity index (CVI) was introduced. The CVI decreases in some pathologies such as DM (13) or HM (14), and it helps differentiating primary central serous chorioretinopathy and that secondary to corticosteroids (15). The study of CVI in HM using this new algorithm would be of great interest.

Other authors introduced deep-learning algorithms for automatic measurements of the choroid. *Table 1* summarizes their main features. The work of Li *et al.* (11) is also included in this table.

In conclusion, it is difficult to obtain automatic measurements in patients with HM, and developing new algorithms such as that introduced by Li *et al.* (11) will be very helpful for future research and for other authors. It would be of interest proving this deep-learning algorithm outside the environment where it was created, in order to check its efficacy in different conditions and human races. It would be interesting as well to prove its efficacy in obtaining automatic measurements around the optic nerve head, as stated by the authors, because it is the location where the ICC was lower.

## Footnote

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